Influence of Threat Occurrence and Repeatability on the Sense of Embodiment and Threat Response in VR

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ICAT-EGVE (2020)
F. Argelaguet, M. Sugimoto, and R. McMahan (Editors)

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Figure 1: *Overview of the virtual environment representing a factory (left), an avatar representing a user placing an ingot on the plate arrived on the conveyor lay (center) and the crusher threatening the user by suddenly going down while the user's hand is under it.*

Abstract

Does virtual threat harm the Virtual Reality (VR) experience? In this paper, we explored the potential impact of threat occurrence and repeatability on users' Sense of Embodiment (SoE) and threat response. The main findings of our experiment are that the introduction of a threat does not alter users' SoE but might change their behaviour while performing a task after the threat occurrence. In addition, threat repetitions did not show any effect on users' subjective SoE, or subjective and objective responses to threat. Taken together, our results suggest that embodiment studies should expect potential change in participants behaviour while doing a task after a threat was introduced, but that threat introduction and repetition do not seem to impact the subjective measure of the SoE (user responses to questionnaires) nor the objective measure of the SoE (behavioural response to threat towards the virtual body).

CCS Concepts

• ***Human-centered computing*** $\rightarrow$ ***User studies; Virtual reality;***

1. Introduction

It has now become widely considered that the success of Virtual Reality (VR) experiences involving avatars relies greatly on users' embodiment towards them [SNB*17; MDB*19]. Achieving a satisfying user embodiment then has become a striking constraint in the development of such applications and has reinvigorated the need to understand the process underlying the perception of avatars. For this reason, the study of virtual embodiment has received much attention as well as the different possible methods to measure it. Among them, the study of the Sense of Embodiment (SoE) is widely used to assess how users perceive their avatars and whether they accept or reject their virtual body. The SoE is usually determined by the use of subjective questionnaires such as the one suggested by González-Franco and Peck [GP18]. However, the use of objective measures of the SoE is being increasingly frequent in embodiment studies. For instance, Kilteni et al. showed that people with higher SoE experienced high behavioural changes [KBS13]. Yet, the more common objective measure of the SoE remains to this day the response to a virtual threat towards the avatar.

Indeed, some research successfully showed that the SoE was correlated with the response to a virtual threat towards the virtual body [YS10; ZH16], and that this response could be objectively measured by galvanic skin conductance [YS10], change in user body motion [FAHL18] or brain imagery [EWW*07; GPRS14]. Such findings are particularly seducing as they suggest that response to a virtual threat can be used as an objective measure of the SoE. Nevertheless, while the introduction of a virtual threat in virtual embodiment studies is widely used, no research has specifically evaluated the impact of the virtual threat on the SoE. In other words, is the SoE modulated by the actual occurrence of the threat?

For example, the stress induced by threats can be detrimental to cognitive functions such as spatial working or memory [MAGR96]. More precisely, a study from Christensen et al. [CDBH19] showed that fear induction was detrimental to the sense of agency of users towards their actions. While these studies were not conducted in VR, we may wonder if a virtual threat would impact similarly user cognitive functions and possibly their SoE.

Moreover, a virtual threat unlike a real threat has no nociceptive feedback corresponding to the event, although visual, acoustic and haptic feedback can be provided. While in most studies a threat is only introduced at the end of the experiment [PE08; GE12], in other studies the threat can be repeated multiple times [ZH16]. Hence, the repetition of a threat in virtual reality may lead to decreased relevance of the illusion and thus less response from the participants. The main scope of this paper is therefore to explore the impact of threat occurrence and repeatability on the SoE and threat response. To that aim, we conducted an experiment ($n = 60$) in which participants were embodied in a virtual avatar, and performed a task in which a threat towards the virtual body was introduced a first time, then repeated several times through the experiment. The SoE of participants as well as their subjective response to threat were assessed through subjective questionnaires before the introduction of the threat, after a first introduction of the threat and after all the repetitions of threat occurrence. In addition, threat response w as also assessed through objective measures by observing participants' physical response to the threat stimuli, as well as potential behaviour adaptations while performing the task after a threat was introduced. A control group did the same experiment with no threat introduced during the task.

2. Background

The SoE is widely used to assess how users perceive their avatars and whether they accept or reject this virtual body. Kilteni et al. [KGS12] divides it into three subcomponents: the sense of ownership (one's self-attribution of a body), the sense of agency (feeling of control over actions and their consequences) and the sense of self-location (one's spatial experience of being inside a body). While the SoE is commonly assessed by the use of subjective measures such as questionnaires [GP18], objective measures of the SoE also tend to be explored. Among them, the introduction of a threat has become a popular mean to assess if users are well embodied in their avatar. This practice relies on the assertion that if users react to a virtual threat towards their virtual body, they must have a strong SoE towards it. Several studies indeed showed that the sense of ownership towards a body was connected with increased affective response to threat towards the body [YS10; ZH16].

2.1. Threat Response and Body Ownership

The first studies exploring the relation between body ownership and response to threat were based on the rubber hand illusion. Armel et al. [AR03] were among the first ones to show that response to a threat towards a rubber hand was linked to the assimilation of the rubber hand as into own's body image. The threat response was in that case assessed by skin conductance response (SCR), e.g., if the rubber hand was "injured", participants displayed a higher skin conductance. Rapidly, the use of a threat has been extended to illusions targeting deeper explorations of the body sense of ownership. For instance, SCR measures after a threat introduction have been used to show that amputees of an upper-limb could feel ownership towards a rubber hand prothesis [ERS*08], but also that it was possible to feel ownership towards supplementary limbs [Ehr09; GPE11], or over an entire body in the context of body-swapping experiences [PE08; GE12]. Quickly, research exploiting the use of a threat to measure the sense of ownership has been brought to virtual reality. Yuan and Steed [YS10] were the first ones to transpose the rubber-hand illusion in Immersive Virtual Reality (IVR) and by the same time the first ones to use SCR as a measure of ownership when a threat is introduced. While Ma et al. [MH13] however questioned their findings in that they did not consider it succeeded in proving that SCR to threat was linked with ownership, it is in contradiction with other research using SCR to threat as an objective measure of ownership [ZMH15; HEH*08]. Other research tried to use different measures of threat response, such as heart-rate deceleration [SSSB10], brain activity pattern [EWW*07; GPRS14] or physical avoidance of threat [GPSS10; KNSS12]. In addition, various types of virtual threats were also explored. It is common in VR to have the threat induced "by itself", like a virtual knife flying in the air and stabbing the virtual body [GPRS14; ZMH15; ZH16], although some studies did use virtual characters in order to introduce a threat [SSSB10; DFA*19]. In addition, the threats may also differ by the way they are introduced [LLL15]. A threat may be introduced with a goal of "surprise", in order to observe the direct physical response of participants to a sudden threat towards their virtual body [ZMH15], while threats can also be present in the Virtual Environment (VE) from the beginning, with participants needing to avoid them in order to perform the task [AHTL16]. Moreover, virtual threats in embodiment studies also vary by their frequency and time of occurrence. Most of the time, the threats are introduced at the end of the experiment [GE12; GPE11] but they sometimes occur repeatedly [GPRS14; MH13]. Finally, we may consider the differences of feedback used in embodiment studies to accompany the threat, which may be strictly visual [DFA*19] or associated with tactile stimulation [MH13] or sound [ZH16].

2.2. Impact of Virtual Threat on the SoE

The introduction of threat in embodiment studies has thus already been widely used as an objective measure of the SoE. Yet, no research has been conducted to evaluate the actual effect of introducing a virtual threat on the subjective measures of the SoE. Indeed, while the response to a virtual threat is used as a measure of the SoE, to our knowledge, it has never been considered as a possible influencing effect. In other words, the response to a virtual threat is associated to a strong SoE towards an avatar, but it was never verified whether its introduction could actually impact an initial SoE. However, some studies showed that stress induced by threats can be detrimental to cognitive functions such as spatial working or memory [MAGR96]. More precisely, a study from Christensen et al. [CDBH19] showed that fear induction was detrimental to the sense of agency of users towards their actions. While these studies do not depict the context of VR, we may wonder if a virtual threat would impact similarly user cognitive functions and possibly their SoE. Furthermore, both immersion and affective content had been shown to impact the sense of presence in virtual environments [BBA*04; GRCP19], a cognitive feeling also widely studied to assess users' perception of virtual environments. Additionally, in most studies a threat is only introduced at the end of the experiment [PE08; GE12], although sometimes it is repeated and occurs randomly[ZH16]. Nevertheless, to our knowledge the impact of threat repeatably on its efficiency has never been assessed. Yet, when a virtual threat is induced to users in virtual reality, they may see their virtual body visually impacted by the threat (collision or even virtual blood), but have no nociceptive feedback corresponding to the event. Hence, it is possible that the repetition of a threat in virtual reality may lead to a decreased relevance of the illusion and thus a diminished response from participants.

3. Experiment

The main scope of this paper is to explore the impact of threat occurrence and repeatability on the SoE and on threat response. The first goal was to study the potential impact of a first threat occurrence on the SoE. The second goal was to observe if the repetition of a threat would impact the way it is perceived by participants, and by extent their SoE. Therefore, in this experiment participants experienced multiple threats occurrences and their SoE was assessed through subjective questionnaires before the first threat occurrence, right after the first occurrence, and finally after all the occurrences at the end of the experiment. A control group did the same experiment with no threat introduced during the task.

3.1. Participants and Apparatus

Sixty participants volunteered to take part in the experiment (30 males and 30 females; mean/S.D. age: 34.1±10.6). They were recruited from the university campus, were naive with respect to the purpose of the experiment and had normal or corrected-to-normal vision. 19 of them had never tried VR, 33 had limited experience with VR and 8 had knowledgeable experience with VR. The study conformed to the declaration of Helsinki. Every participant signed an informed-consent form before the experiment. The experiment was developed using Unity software (version 2018.2.19f1). Participants were immersed in VR using a HTC Vive PRO Head-Mounted-Display (HMD) and equipped with two Vive controllers (one in each hand) and two Vive trackers (one attached to each foot). There were embodied in a gender-matched avatar that was animated using inverse kinematics (Unity FinalIK plugin) using the positions of the HMD, the controllers and the trackers. Avatars were not racially matched.

3.2. Task & Threat

In order to increase the coherence of a potential threat occurrence, we chose to put participants in a VE that represented a factory where potential incidents might happen, e.g., a malfunction of a dangerous machine (see Figure 1, left). More precisely, participants had to perform a task that consisted in grabbing a metallic ingot, putting it on a plate coming on a conveyor lay, then pressing a button so that a crusher smashed the ingot to transform it into a metallic pinion. Before the ingot was placed on the plate, the button remained red, and only if the ingot was correctly placed within rectangular boundaries drawn on the plate, the button would turn green and become pressable. Therefore, participants had to be precise in their gesture. All the task interactions were performed by participants using their dominant hand. Depending of whether participants were left or right-handed, the environment was mirrored symmetrically, e.g., the box containing the ingots as well as the button were placed on the opposite side. Using the original 3D model of the HTC Vive controller, we attached a 3D magnet on top, which participants used to grab the virtual ingot by pressing the controller trigger. To release the ingot, participants simply released the controller trigger. Furthermore, the threat consisted in a malfunction of the crusher, which would suddenly activate while participants were positioning the ingot on the plate (i.e., the participants' hand was still under it). It was accompanied by a threatening sound of a "machine crash". The crusher would go down to the plate, to increase the chances to collide with the virtual arm, by the speed of 2 m/s. The threat was thus designed in a way that would make it plausible for the participants, in order to ensure its efficiency in virtually threatening them. Moreover, a vibration was given through the HTC Vive controller each time the crusher smashed the ingot or malfunctioned.

3.3. Experimental Protocol

Upon their arrival, participants read and signed the experiment consent form and filled in a demographic questionnaire (collecting age, gender and experience in video games and VR). They were then briefed about the experiment and equipped with the HMD, controllers and trackers. Afterwards, avatars were re-scaled so that the dimensions matched the participant's eye-height, as well as arm span, which were computed from the position of the HMD and controllers while the participant held a N-pose. Finally, participants were immersed in the VE. They all started the experiment facing a virtual mirror in the virtual factory, giving them the opportunity to see their full virtual body animated by their own motions. When they were ready to start, the mirror disappeared by mechanically sliding towards the ceiling, and the experiment began. From this point, the experimental flow was divided into three blocks that involved 12 trials each. One trial consisted in performing the task once.

A threat was introduced at the end of the second block (in the 24th trial). The same threat was then introduced again in the third block during trials 26, 30, 33 and 34. A control group of participants was considered for the experiment, for which no threat was ever introduced, meaning that all trials were similar. At the end of each block, participants answered an embodiment questionnaire (an adapted version of González-Franco and Peck's embodiment questionnaire [GP18]) while being immersed in the VE. A virtual television appeared in the factory with questions written on it, and participants answered the questions with the trackpad and trigger of their right controller. Finally, after the last block, participants were unequipped and invited to give general written feedback regarding the experiment. Each trial lasted approximately 5 seconds and participants performed in total 36 trials each. The whole experiment, including welcoming of participants, reading and signing the consent form, and answering questionnaires lasted approximately thirty-five minutes.

3.4. Experimental Design

A mixed-design was adopted for the experiment, considering two independent variables: Group and Block. Group was a between-subject factor with two levels (*threat* and *control*), corresponding respectively to half of the participants (n=30: 15 women and 15 men) that encountered a threat during the experiment and the other half of the participants (n=30: 15 women and 15 men) which performed the whole experiment without experiencing a threat. Block was a within-subject factor with three levels corresponding to the blocks of the experiment flow: *first*, *second* and *third*. Regarding dependent variables, both objective and subjective data were collected during the experiment to assess participants' SoE as well as threat responses.

3.4.1. Collected Data

Subjective Data: Each participant answered a subjective embodiment questionnaire at the end of each block, inspired from the questionnaire proposed by González-Franco and Peck [GP18]. The questions were divided into four categories (Ownership, Agency, Self-Location and Threat). However, since one group did not encounter any danger, only Ownership, Agency and Self-Location were used to compute SoE scores. For the same reason, threat related questions were only analysed for the group with danger. All the questions were answered on a 7-point Likert scale, from -3 (strongly disagree) to 3 (strongly agree), and can be found in Table 1.

Objective Data: In order to assess participants physical response to the threat, as well as potential changes in their behaviour while performing the task after the threat was introduced and repeated, the motion (position and orientation per frame) of the participants' dominant hand was recorded. In addition, the time during which the dominant hand was under the crusher was also recorded for each trial. To gain some insight regarding the objective reaction to threat during the experiment, speed profiles were computed for each participant and each trial. More precisely, we were interested in the direct physical reaction from participants to the threat stimuli, but also the potential impact on user behaviour while performing the task in safe trials (a safe trial is a trial with no threat occurrence, independently of the group of participants).

3.4.2. Hypotheses

In this experiment, we were interested in evaluating the impact of threat occurrence and its repeatability on the SoE and threat response in VR. We first hypothesised that the initial threat occurrence would impact negatively the subjective measure of the SoE. Indeed, some studies showed that the stress induced by threats can be detrimental to cognitive functions such as spatial working or memory [MAGR96]. More precisely, a study from Christensen et al. [CDBH19] showed that fear induction was detrimental to the sense of agency of users towards their actions. While these studies were not conducted in VR, we may wonder if a virtual threat would impact similarly user cognitive functions and possibly their SoE. For this reason, we argue that the SoE could be negatively impacted by the first occurrence of the threat, i.e., that participants would experience a lower SoE after experiencing a threat. We also hypothesised that this first threat occurrence would have an impact on participants behaviour while performing the task afterwards, because of the anxiety being raised by the threat. More precisely, we believed those changes would be visible either by a accelerated speed while doing the task or a decreased time of their dominant hand spent under the crusher. Yet, when considering the repeatability of the threat introduction, the expected the impact on the SoE and Threat response to be different. Indeed, when experiencing a virtual threat in VE, participants encounter visual feedback as well as sometimes auditory or tactile feedback. However, no nociceptive feedback is associated with the virtual threat, which might at some point break the illusion. Hence, because we expected the repetition of the threat to decrease its efficiency in making participants react, we supposed their physical reaction to it would decrease along the repetitions and that their subjective response to the threat (answers to subjective questions about how the threat was perceived) would also be diminished. In addition, we expected the loss of plausibility of the virtual threat to impact negatively the SoE, e.g., that if participants lost conviction of the VE they might also loose conviction of their virtual body. Finally, we expected that these effects would not be present in the control group and therefore not related to the exposure time.

In summary, considering our experimental design, our main hypotheses are as follows.

H1 In the *threat* group, the SoE scores will be lower after the first threat (i.e, lower after the *second* block than after the *first* block.)

H2 In the *threat* group, the SoE scores will be lower after several repetitions of the threat (i.e, lower after the *third* block than after the *second* block as well as than after the *first* block.)

H3 (control) In the *control* group, the SoE scores will remain similar between all blocks.

H4 In the *threat* group, the scores of subjective threat responses (Threat category of subjective embodiment questionnaire) will be lower in the *third* block than in the *second* one.

H5 In the *threat* group, the physical response to the threat will decrease along the repetitions of the *third* block.

4. Results

Mixed two-way ANOVA analyses were performed when comparing scores of SoE between the blocks (within-subjects) and the two groups (between-subjects). The normality assumption was tested using Shapiro-Wilk test and when not verified, an Aligned Rank Transformation (ART) was applied on the data. Tukey's post-hoc tests ($\alpha = .05$) were conducted to check significance for pairwise comparisons. When comparing scores of threat subjective questions, Friedman test was performed between blocks as normality assumption was not verified. As for correlation analyses, Pearson's r (r) was used for parametric data and Spearman's r (r_s) was used for non-parametric data. In addition, post-hoc tests were corrected using Bonferroni correction.

4.1. Subjective measure of the SoE

The embodiment scores were computed by averaging the scores of Ownership, Agency and Self-Location. As previously said in Section 3, Threat scores were not included in the SoE computation

Table 1: *Questionnaire used in the experiment. Questions in italics are control questions.*

Variable	Question
Ownership	O_1) I felt as if the virtual body I saw when I looked down was my body. O_2) *It felt as if the virtual body I saw was someone else.* O_3) *It seemed as if I might have more than one body.*
Agency	A_1) It felt like I could control the virtual body as if it was my own body. A_2) The movements of the virtual body were caused by my movements. A_3) I felt as if the movements of the virtual body were influencing my own movements. A_4) *I felt as if the virtual body was moving by itself.*
Self-Location	SL_1) I felt as if my body was located where I saw the virtual body. SL_2) *I felt out of my body.* SL_3)I felt as if my (real) body were drifting towards the virtual body or as if the virtual body were drifting towards my (real) body.
Threat	T_1) I felt that my own body could be affected by the crusher. T_2) I felt a fear sensation in my body when the crusher malfunctioned, if it did. T_3) When the crusher malfunctioned, if it did, I felt the instinct to move my hand. T_4) I had the feeling that I might be harmed by the crusher.

since one group did not encounter any threat. A mixed-two way ANOVA (group, block) analysis was performed on embodiment scores as well as on each sub-component. We did not find significant differences between the embodiment scores depending on the block or the group, or their interaction, which thus does not support **H1** nor **H2**. The general mean score are 1.77±0.67 (S.D.) for embodiment, 1.12±1.16 (S.D.) for ownership, 2.30±0.58 (S.D.) for agency and 1.87±0.91 (S.D.) for self-location.

Although not significant, the here-above analysis highlighted a tendency for Ownership scores to decrease from block 1 to block 3. We thus decided to perform a mixed-two way ANOVA (group, block) analysis on each question of ownership independently, which highlighted a significant order effect for O_1 and O_3 from Ownership questions ([$F_{2,116}$=4.26, $p < .05$] for O_1 and [$F_{2,116}$=8.55, $p < .001$] for O_3). Post-hoc tests showed that O_1 scores were significantly lower in block 2 than in block 1 (p<.05) and that O_3 scores were higher in block 2 that in block 1 (p<.05) and higher in block 3 that in block 1 (p<.001). These results suggest that the repetition of the experimental blocks had an negative impact on some questions related to subjective Ownership, independently of whether a threat was introduced or not during the experiment, which does not allow the validation of **H3**.

4.2. Subjective Response to Threat

Subjective responses to the threat were analysed in two groups: Event Related questions (**ER**) refers to the two questions directly related to the occurrence of a threat (T_2 and T_3), and Non Event Related questions (**NER**) refers to the questions related to general fear towards the crusher (T_1 and T_4). Friedman tests were performed to analyse responses to **ER** questions only in the *threat* group, as no threat was introduced in the *safe* group. Significant differences depending on block were found for each question (T_2: χ^2=34.7, $p < .0001$, T_3: χ^2=42.0, $p < .0001$). Wilcoxon tests were thus conducted and showed that threat scores were significantly lower in the *first* compared to the *second* block for the two questions (p<.0001) and in *first* compared to third *third* block (p<.0001). However, no significant difference was found between blocks *second* and *third* (see Figure 2 First and Second). Subjective **ER** threat response thus increases after a first threat occurrence, but does not further increase nor diminishes after several repetitions.

NER questions were analysed for both groups, and a mixed-two way ANOVA analysis was also performed on both questions independently. For both questions, significant effects of group ([$F_{2,58}$=19.37, $p < .001$] for T_1 and [$F_{2,58}$=14.03, $p < .001$] for T_4), block([$F_{2,116}$=5.41, $p < .01$] for T_1 and [$F_{2,116}$=20.22, $p < .001$] for T_4) and interaction between the two ([$F_{2,116}$=11.49, $p < .001$] for T_1 and [$F_{2,116}$=8.56, $p < .001$] for T_4) were found. For T_1 and T_4, post-hoc tests showed that ratings in the *second* and *third* blocks were higher than in the *first* block (p<.0001) for group *threat*, but not for *safe* group (see Figure 2 Third and Fourth). Similarly to **ER** response, these results suggest that subjective **NER** threat response increases after a first threat occurrence, but does not further increase nor diminishes after several repetitions. Hence, these results do not support **H4**.

4.3. Objective Response to Threat

In this analysis, we were interested in comparing objective data depending on trials to search for potential evolution in user behaviour due to threat introduction and repetitions. We thus considered Trial as another independent variable.

4.3.1. Time of the dominant hand being under the crusher

We were interested in the time the participant's dominant hand spent under the crusher during each trial (see Figure 4), as an information of how "scared" they might be of their hand being potentially crushed while doing the task. More precisely, we were interested in all the safe trials (in which no threat was introduced) ranging from the last safe trial before a first threat was introduced to the last safe trial of the experiment (23, 25, 27, 28, 29, 31, 32, 35 and 36). Five outlier samples were removed for this analysis due to abnormal time values in a few trials, corresponding to a time of either 0s (rare cases in which participants threw the ingot and had it placed perfectly on the plate) or an excessively abnormal time under the crusher (in some situations where participants were scared of the crusher and had to make several attempts to place correctly the ingot under the plate).

A one-way ANOVA was performed on the data from the *threat* group to investigate differences of time among the selected safe trials, and highlighted a significant effect ([$F_{8,232}$=4.05, $p < .0001$]). Post-hoc tests only showed significant effects between trial 23 and all other trials, except 25: the time that the dominant hand spent

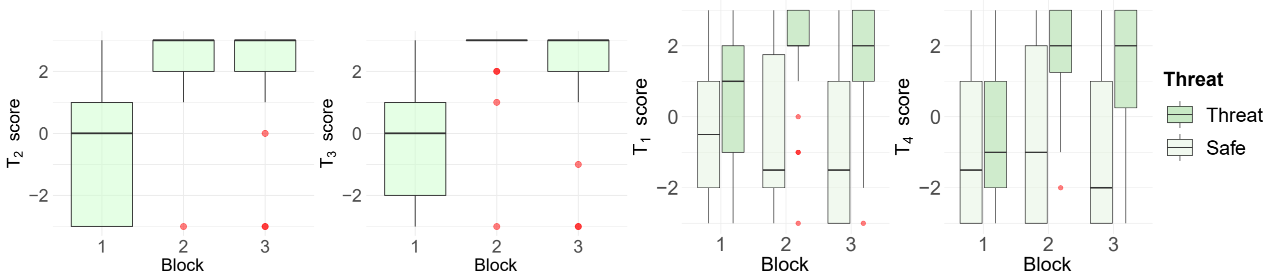

Figure 2: *First and Second: Mean scores of ER threat subjective questions for the threat group. Third and Fourth: Mean scores of NER threat subjective questions.*

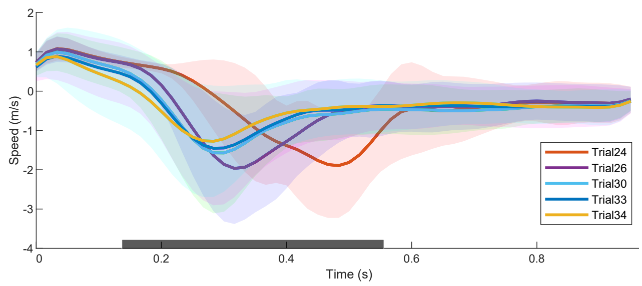

Figure 3: *Averaged speed profiles of participants during threat trials. SPM analysis highlighted significant differences between trials on the time section indicated by the grey band.*

under the crusher was not significantly lower in the trial following the first threat (25), compared to the trial preceding it (23), but the time in the other safe trials were all significantly lower than trial 23 (p<.05). A one-way ANOVA was also performed in *control* group and did not show any significant differences between the investigated trials ([$F_{8,232}$=0.53, p = .83]). This result suggests that after the threat was introduced twice, participants left their hand a shorter amount of time under the crusher, and thus performed the task faster. The fact that this change of behaviour is not visible in the control group also suggests that this change is due to participants' reaction to the threat.

4.3.2. Speed Profiles

For each trial, the speed profiles of the dominant hand while performing the task were computed for each participant, then averaged across participants. More precisely, for the trials in which a threat occurred, the speed profiles were computed from the time the threat occurred and for the trials with no threat, the speed data were aligned between participants on the time the virtual ingot was released from the dominant hand. Data were then cropped in order to ensure having the same length of data for each participant (for trials with a threat, we kept the 80 frames following the frame of the threat introduction, and for safe trials we cropped from 50 frames before the ingot was released to 50 frames afterwards). In addition, to include information about the direction of the hand movement in the analysis, we considered speed values of movements away from the participant (along the X axis, i,e., towards the machine) to be positive, while speed values of movements towards the participant (along the -X axis, i,e., away from the machine) to be negative. This representation enabled us to observe simultaneously the magnitude of the movement of participant's dominant hand, as well as its direction (see Figure 3). To analyse the speed profiles, we resampled them at a frequency of 60 Hz, then we filtered the data with a butterworth low-pass filter with a cutoff frequency of 30 Hz to reduce the noise. We evaluated the effect of Trial on the speed profiles using Statistical Parametric Mapping (SPM) methods [Fri94]. This process allows comparing time series data taking into account their variability at each time frame.

Motion data in threat trials: We used SPM analysis to compare speed profiles of threat trials (Trial = 24, 26, 30, 33 and 34) in the *threat* group, which showed a significant effect of Trial (p<.001). Post-hoc tests revealed a significant difference between trial 24 (first threat introduction) and all other trials (26, 30, 33 and 34) (p<.05). Qualitatively, we can notice that the maximum speed remains comparable among trial 24 and the others, while displaying a temporal shift: on trial 24, participants reacted significantly slower to the threat than in the other trials (see Figure 3).

Motion data in safe trials: We used SPM analysis to compare speed profiles of specific safe trials in both *threat* and *control* groups. Since we were interested on the impact of threat repetitions on behaviour in safe trials, we compared the first trial (1), the trial before (23) and after (25) the first threat, and the last trial (36). SPM analysis showed a significant effect of Trial on speed profiles (p<.001) in both groups, on two distinct phases: the forward motion of the dominant hand, and the backward motion. In the *threat* group, post-hoc tests showed significant differences between the last trial of the experiment and trials 23 and 25, yet only in the forward motion (p<.05) (see Figure 5). This result shows that in average the approaching speed was higher for the *threat* group for the last trial. Overall, those results do not support **H5**, as the repetition of threats did not impact physical threat response.

5. Discussion

The main objective of this paper was to investigate the impact of threat occurrence and repetition on users' SoE and threat response. We hypothesised that a single threat occurrence would decrease participants' SoE towards their avatar, and even more after threat repetitions. In addition, we expected threat repetition to cause a decrease in participants response to threat. In this section, we discuss our results regarding the impact on threat responses and the impact of the threat on the SoE. Finally, we discuss the potential impact of threat on participants' behaviour.

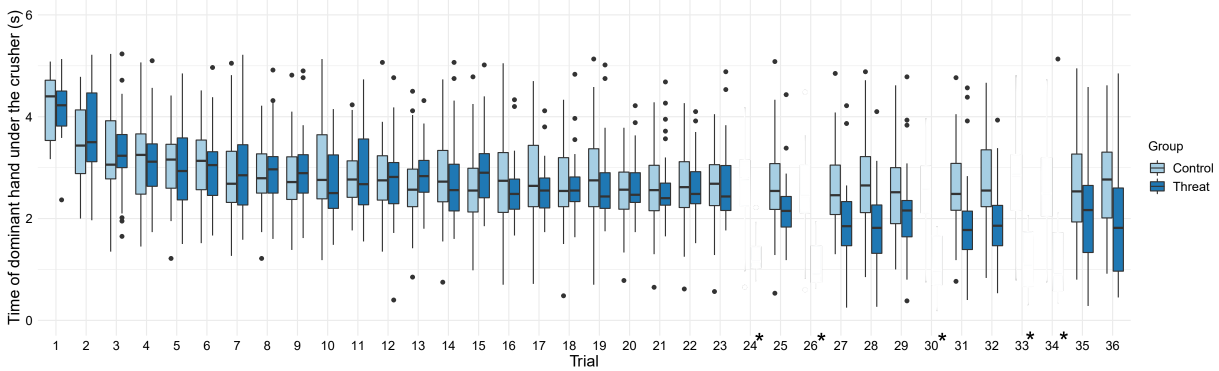

Figure 4: *Mean time the dominant hand spent under the crusher per trial per group. Asterisks identify trials in which a threat was introduced, and are therefore masked for that the time spent under the crusher in those trials is not comparable with other trials.*

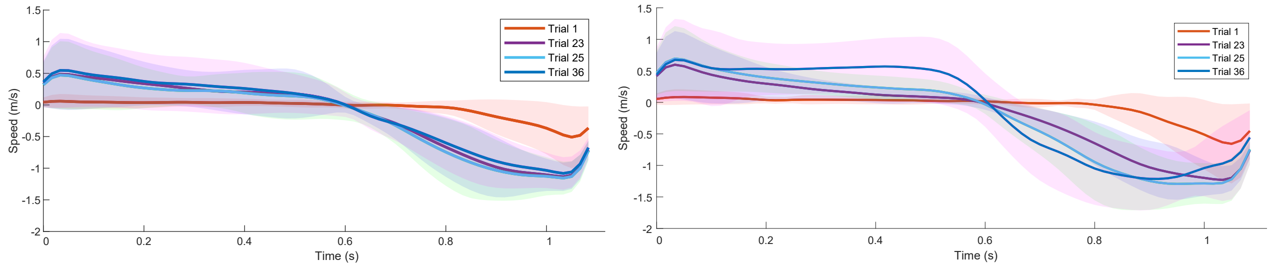

Figure 5: *Averaged speed profiles of participants during selected safe trials in the control group (left) and the threat group (right). The sign of the y-axis represents the direction of the motion, positive speeds represent the user moving his hand forward to place the ingot and negative speeds repents the user moving his hand away from the crusher.*

5.1. Threat Responses

Subjective and objective data of threat response were collected for two main reasons. First, we wanted to verify that participants reacted to the threat we had designed, which was validated by both the subjective and behavioral responses. Participants from the *threat* group significantly reacted to the threat introduction by a fast withdrawal of they hand, visible in the results by a significant speed peak of their dominant hand when the threat occurred (Figure 3). They also rated a strong subjective feeling of fear towards the crusher when it malfunctioned (Figures 2). Second, we were interested in the impact of threat repetition on the way it was perceived by participants. We indeed had the hypothesis that the repetition of the threat would impact its credibility due to the absence of nociceptive feedback, and that in consequence participants would loose faith in it and stop reacting. However, this was not observed in our results. The subjective ratings regarding the fear induced by the threat were in the third block as high as the ratings in the second block, which did not support **H4**. Regarding the objective data, speed profiles only highlighted a difference between participants speed profiles in the first threat introduction and all the other threat occurrences. More precisely, the average speed peak remained similar for all threat trials (around 2m/s), but the peak was shifted: the first time the threat occurred, participants took more time to react to the threat than in the other threat trials. While we would have expected the speed peak to decrease along the repetitions of threat, we can notice in Figure 3 that although not significant, the speed peak tends to diminish in the last threat trials (30, 33 and 34). Although some adaptation is observed along the experiment, the current results do not support that the repetition of a threat alters physical threat response (**H5**). Nevertheless, we may wonder whether the number of threat repetitions was sufficient, which is why we address this matter in Section 5.3.

As we can see in Figure 5, our results also highlighted changes in user behaviours in the safe trials that occurred after the threat occurrences. Before the ingot was released ($t \approx 0.6s$), we can observe that the approaching speed increased in both groups. Yet, we can observe that this effect is higher, and significant, in the last trial of the danger group. By increasing the approaching speed, participants seem to have tried to avoid “more” the threat after several threat occurrences. Yet, interestingly the subjective data does not support an increased fear towards the crusher by the end of the experiment. This result is also coherent with results regarding the time that the dominant hand stayed under the crusher. Yet, these last results also highlighted that participants’ behaviour seemed to be impacted only by the second threat occurrence rather than the first one. We therefore believe it would be interesting in future work to explore whether one threat is enough to impact users behaviour and for which reason.

5.2. Threat Occurrences and SoE

The results regarding the subjective measure of the SoE did not show any impact of the threat first occurrence nor of its repetition, which thus does not fulfill our hypotheses (**H1** and **H2**). According to the work of Christensen et al. [CDBH19], we expected the fear induced by the crusher malfunctioning to negatively impact the sense of agency of participants. Christensen et al. have indeed shown that fear expectation alters users' sense of agency. Their study was inspired from the work of LeDoux [LeD03], which states that fear is associated with automated behavioural patterns. Indeed, fear commonly induces automatic withdrawal responses or action inhibition (e.g., fleeing or freezing) [CDBH19]. We indeed observed such patterns in the participants' response to the crusher malfunction, as visible for instance in Figure 3, which highlights a speed peak when participants moved their hand backward from the machine after a threat was introduced. However, while Christensen et al. found an impact on users' sense of agency, no impact was found in our study on users' sense of agency towards their avatar, nor over their SoE. Nevertheless, we must emphasize two main differences between the study of Christensen et al. and our study. First, their study was not conducted in virtual reality, and the sense of agency thus did not refer to the control of a virtual avatar. Moreover, in their study they specifically informed participants that in some blocks of trials, no threat would ever be introduced, and that in other blocks one or several threats might occur. Participants were thus perfectly aware of when they were to expect a threat or feel safe. In our implementation, this was not transparent for participants. In the consent form participants signed, they were briefed that a "malfunction of the crusher" could occur, with no more precision. We must consider that, entering the experiment, participants might have been in a "threat expectation" state. It would thus be interesting to replicate this study being transparent with participants on when a threat could occur or not, e.g., to measure whether we are able to replicate Christensen et al.'s results.

Moreover, our threat was designed as in most embodiment studies [GPRS14; ZMH15], in a way that it would visually affect the integrity of the virtual body by colliding with it. After verification in the analysis, we found that over 150 trials with a threat, the crusher collided 128 times with the dominant hand of participants (mean/S.D. time of collision in seconds: 0.21 ± 0.10). Other times, participants might have withdrawn their hand too fast, but in all cases participants experienced a vibration on the controller when the threat happened. This vibration was important as it is a common fact that mismatches between what you see (e.g. an object touching your avatar) and what you feel (e.g. tactile feedback) decrease the SoE towards the avatar [KGS12]. However, we must acknowledge that the coherence between visual input and tactile feedback differs within experiences. For instance, the coherence between visual and tactile is not the same whether the participants' hand is virtually brushed while being brushed simultaneously in the physical world [HANL16], or if the participants' hand is virtually harmed by a knife while receiving a vibration in the physical world [MH13]. The notion of coherence in VEs has been shown to be of great importance to have participants react realistically to the VE [Sla09]. In our experiment, no nociceptive feedback was associated with the virtual threat. For this reason, we expected this lack of coherency to negatively impact threat response along the threat repetitions (**H5**). However, even though participants noticed and reacted to the threat, the quickness of the threat in our experiment might have prevented participants from observing the actual collision, which could be a possible reason why we did not observe a decrease of the physical response to the threat in the last block. It would thus be very interesting in future work to investigate the potential impact of mismatch between tactile feedback and virtual threat on the SoE.

Our results also highlighted a sequential effect of the repetition of the blocks on two ownership questions, which was also present in the control group and therefore did not allow the full validation of **H3**. However, it remains unclear whether scores were impacted by the duration of the experiment (i.e., it would then impact negatively the illusion of ownership), or by the repetition of questionnaires regarding the sense of embodiment (i.e., which may lead to an increased attention given to the virtual body, and put in evidence artefacts that would affect the illusion).

5.3. Limitations

When designing our experiment, a number of choices were made regarding the implementation of the threat. As presented in Section 2, there exist many different kinds of threats in the literature in embodiment studies. We decided to make coherence the main aspect of our threat, placing it in a realistic context where an accident is likely to happen. In addition, our threat was associated with auditory and tactile feedback and was conceived to collide with the virtual body. All those choices made in the experiment can potentially bias the results, and therefore, it would be interesting to validate that our results generalize to other threats, or at least to similar types of threats. For instance, while we expected participants to be conscious of the collision of the threat with their virtual body, we believe that replicating this experiment with a threat that makes the collision more obvious would be interesting. Furthermore, the length of the experiment could have also played a role in the results. Indeed, although not significant, we observed adaptation patterns that appeared in the motion profiles. In the experiment, we decided to keep a low number of threat repetitions as most experiments keep a low number of threat repetitions and to reduce fatigue. Nevertheless, changes in the physical reactions of the participants might become more obvious with a longer exposure, and it remains unclear if these changes would remain between VR sessions.

6. Conclusion

In this paper, we explored the potential impact of threat occurrence and repeatability on users' Sense of Embodiment (SoE) and threat response. The main results show that the introduction of a threat does not alter users' SoE but might change their behaviour while performing a task after the threat occurrence. In addition, threat repetitions did not show any effect on users' subjective SoE, or subjective and objective responses to threat. Taken together, our results suggest that embodiment studies should expect potential changes in participants behaviour while doing a task after a threat was introduced, but that threat introduction and repetition do not seem to impact the subjective measure of the SoE (user responses to questionnaires) nor the objective measure of the SoE (behavioural responses to threat towards the virtual body).

Acknowledgments

We wish to thank participants of our experiment. This work was sponsored by the Region Bretagne and the Inria Avatar Challenge.

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